PHYSICAL MODELING FOR COMPLEX HYDRAULIC STRUCTURES (MAIN PUMPING STATION CASE STUDY)

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ABSTRACT

In order to verify and validate the design of any complex hydraulic structure such as our case study, which presenting a wastewater main pumping station with a design flow (12 m^3/s), a physical modeling has been built to simulate the hydraulic and operational scenarios over the various anticipated operating ranges and operating combinations in order to identify the adverse operating conditions.

The purpose of the testing is to establish the operating characteristics of the system and to develop the design, where considered necessary, to achieve a satisfactory hydraulic environment over the full range of inflows, pump combinations and water levels. The testing and development work undertaken on a physical hydraulic model of the raw sewage pumping station.
The model was constructed to a scale of 1/8th full size and operated on the basis of Froude law similarity. The model was tested under various critical scenarios across its full operating range (1 m^3/s to 12 m^3/s).

Testing of the model has proved the suitability of the pumping station’s design. The testing and demonstration of the model proved the suitability of the pumping station configuration as per the applied developed model arrangements and plan setting geometry. The model testing has confirmed the general arrangement of the pumping station and identified various minor improvements.

Keywords: Complex Hydraulic Structure, Physical Model, Pre-Swirl, Vortice

▪ MODEL DESIGN

The raw sewerage pumping station will compromise six screen channels and three sumps. Each sump will have the potential to house eight submersible pumps, with the pumps initially operating on a six duty, one stand-by basis, with space remaining within each sump for a single extra pump. Each pump will be capable of delivering 1m^3/s.

The sumps will operate on a duty / assist basis with two screens serving each sump. Each sump includes a ported baffle wall to help distribute flow uniformly to the pumps. The station also includes a series of diversion penstocks upstream of the pumps to distribute flow to each of the sumps as required [2].

▪ SIMULATION LAWS

The Froude and Reynolds numbers are used for the model simulation and the extrapolation of results with respect to the prototype design[4].

a. Froude number (Fr):

It corresponds to the ratio between the inertia forces and gravity forces. The Froude number should be kept between prototype and model. Under these conditions, for a geometric ratio λ between the prototype and the model, the velocities are in the ratio $\lambda^{0.5}$ and flows are in a $\lambda^{2.5}$ ratios.

b. Reynolds number (Re):

It corresponds to the ratio between inertia forces and viscous forces. It is necessary to choose a sufficient model scale to ensure the effects of viscosity are negligible during the test.

MODEL SCALE

According to the previous F_r& R_e similitude laws, the 1/8 model scale has been selected to comply with the requirements and having a reasonable ratio between model size and results accuracy. Figure number (1, 2 &3) is illustrating model [2].

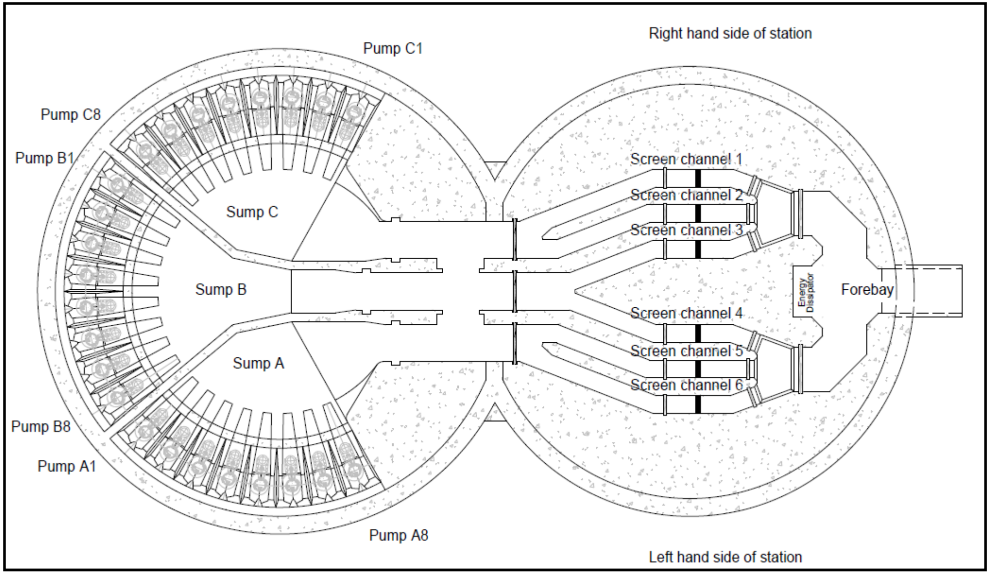

Figure (1) Model Plan View (Scale: 1/8)

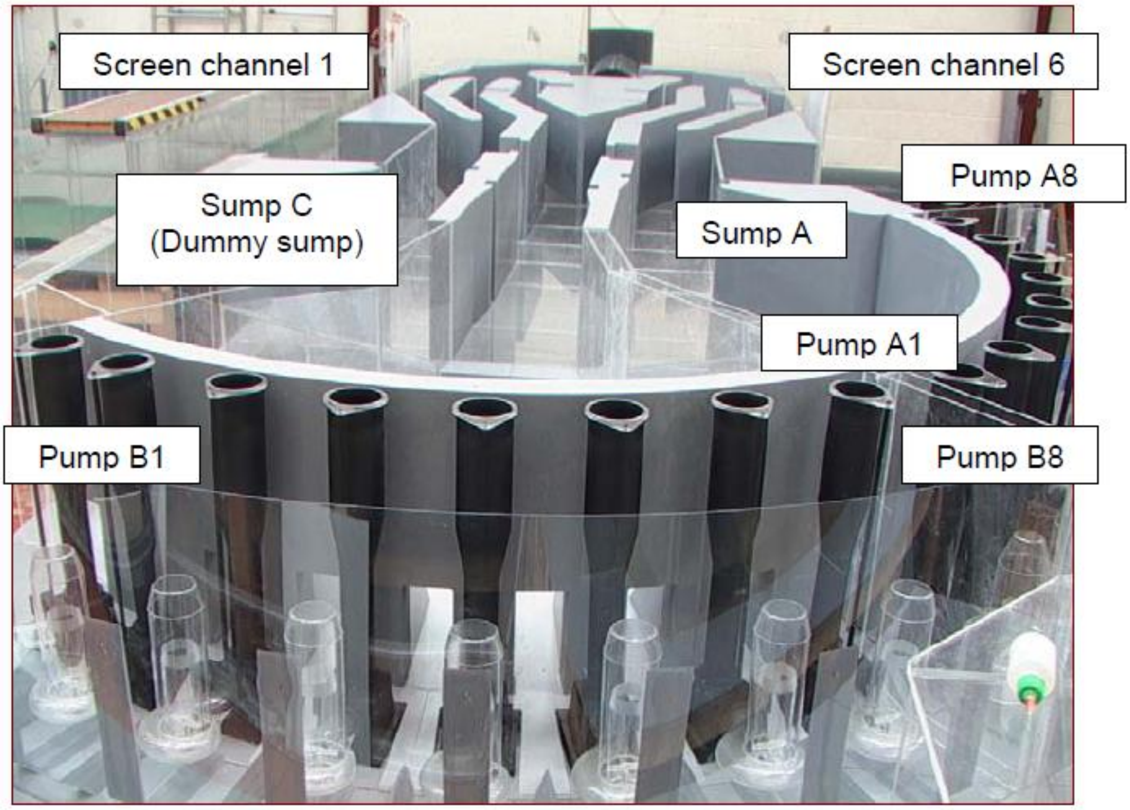

Figure (2) Model Overall View (Scale: 1/8)

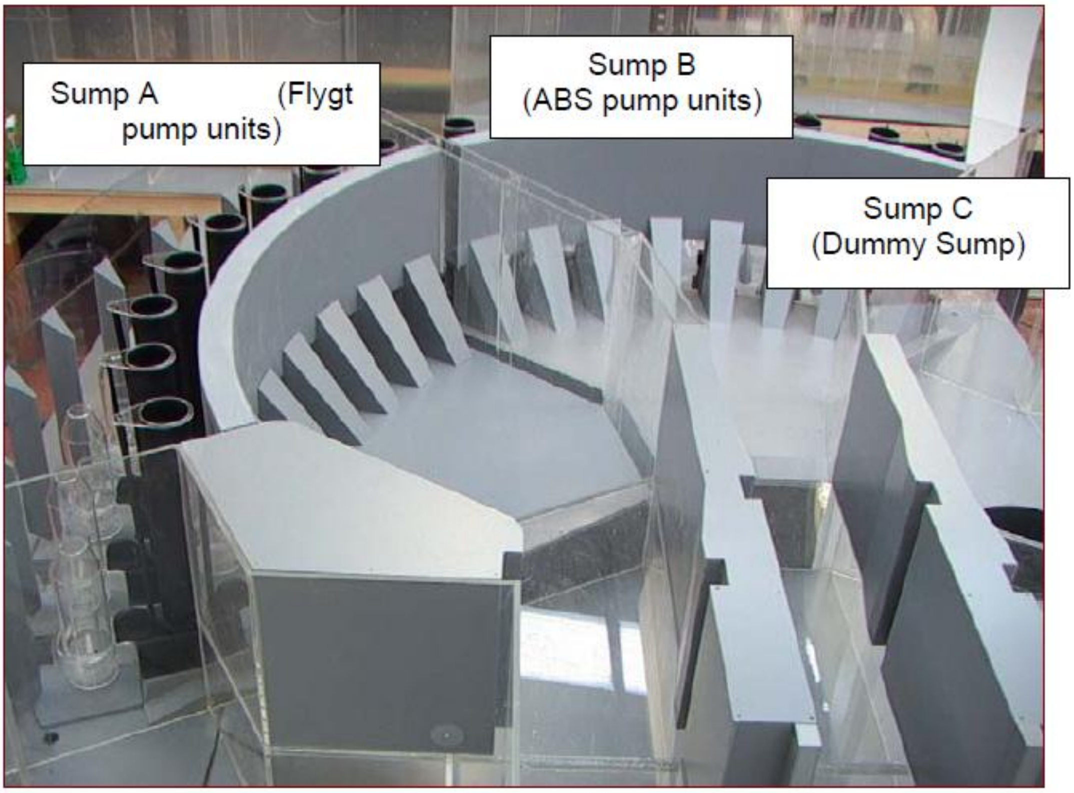

Figure (3) Model Sump Layouts

MODEL TESTING SCENARIOS

The model was tested as per the following standards and criteria:

Pre-swirl

The maximum permitted swirl angle should be 5 degrees for both short term and long term average conditions [1].Whilst 7 degrees have been defined as acceptable as a short term maximum value for infrequent occurrence (<10% time). We would not consider this acceptable and would aim to achieve a time averaged and short term peak pre-swirl value not exceeding 3 degrees.

Free surface vortices

Surface vortices should not exceed Type 3 classification [1]. Due to scale distortions, air core vortices will be more pronounced at full scale, it is therefore proposed that surface vorticity should not exceed Type 1 within the model [6].

Submerged vortices

Submerged vortices should not exceed Type 2 classification [1]. In view of the potentially destructive nature of these vortices, we would seek to eliminate all submerged vortex types by the development of appropriate benching local to the pump intakes.

Flow regime

The screen channels should provide an even velocity distribution, free from excessive turbulence. The channels should be smooth and regular and avoid leading edges that may potentially collect screenings and low velocity areas that may collect grit [5].

Velocity

A minimum velocity of 0.5 m/s is advised to prevent the accumulation of grits within the screen channels. A maximum velocity of 1.0 m/s to 1.5 m/s (refer to manufacturers detailed requirements), is recommended to prevent screenings, scour and potential punch through [4].

Air intake

Air ingestion to a pump intake may cause a reduction in pump capacity. It is widely recognized that ingestion of air concentrations in excess of 4 % by volume may cause a significant reduction in pump capacity [1]. The expansion of ingested air bubbles within the low pressure regions of the pump impeller may result in mechanical imbalance forces, which may result in vibration and an acceleration of mechanical wear. In addition, prolonged air ingress may result in air pocket development within the rising main, which may cause instability and blockage [6].

In view of the potentially destructive nature of air ingress to a pump intake, we would seek to prevent all bulk air passage to a pump intake. Bulk air is defined as small but defined air bubbles [4].

The following figures numbers (4, 5, 6, 7, 8, & 9) are illustrating the various hydraulic and operational scenarios over the anticipated operating range and operating combinations:

Figure (4) Pump Coherent Submerged Vortices

Figure (5) Flow Patterns in Sump with Oil & Grease

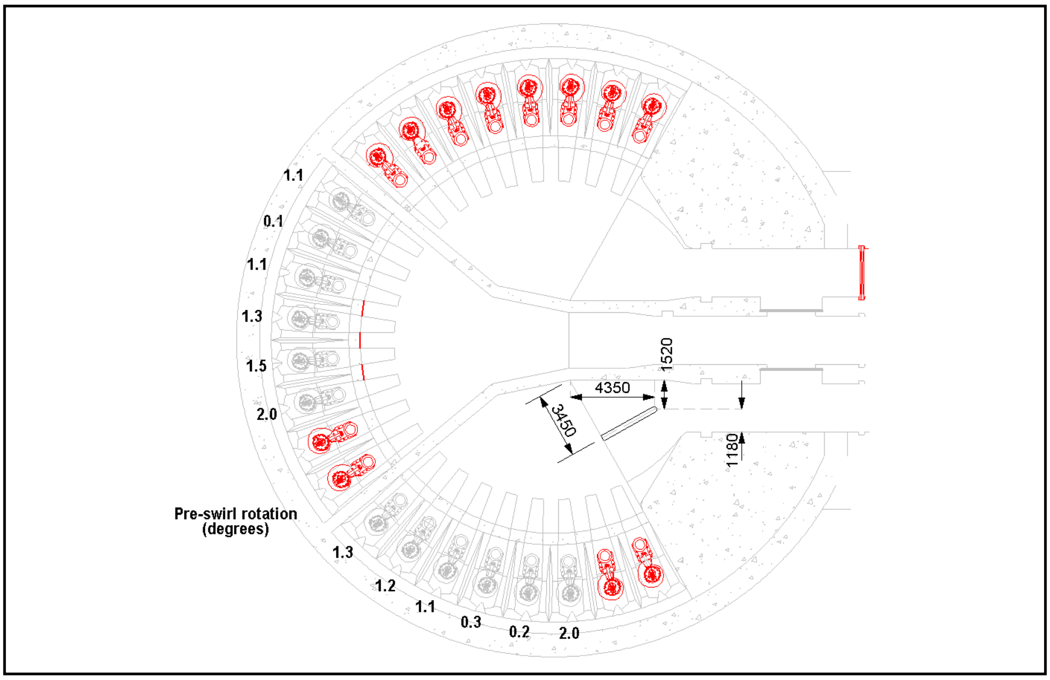

Figure (6) Pre-swirl Rotation

Figure (7) Ultimate Flow Water Levels & Inlet Energy Dissipation (Forebay@ 12 m3/s)

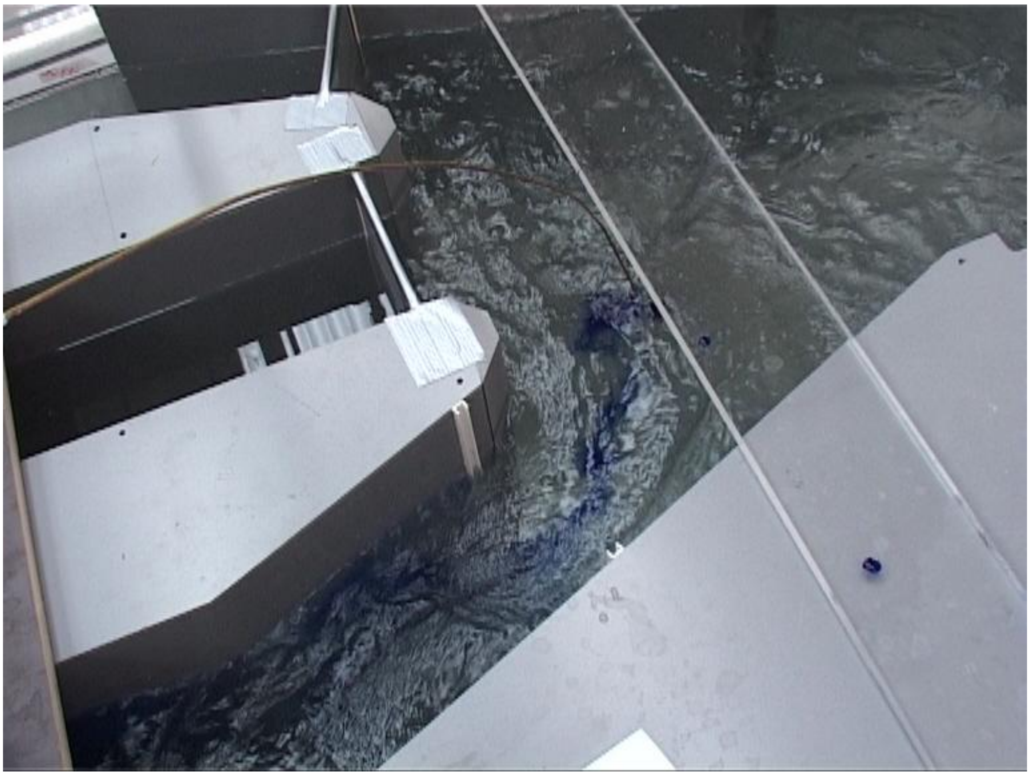

Figure (8) On Approach to screening channels

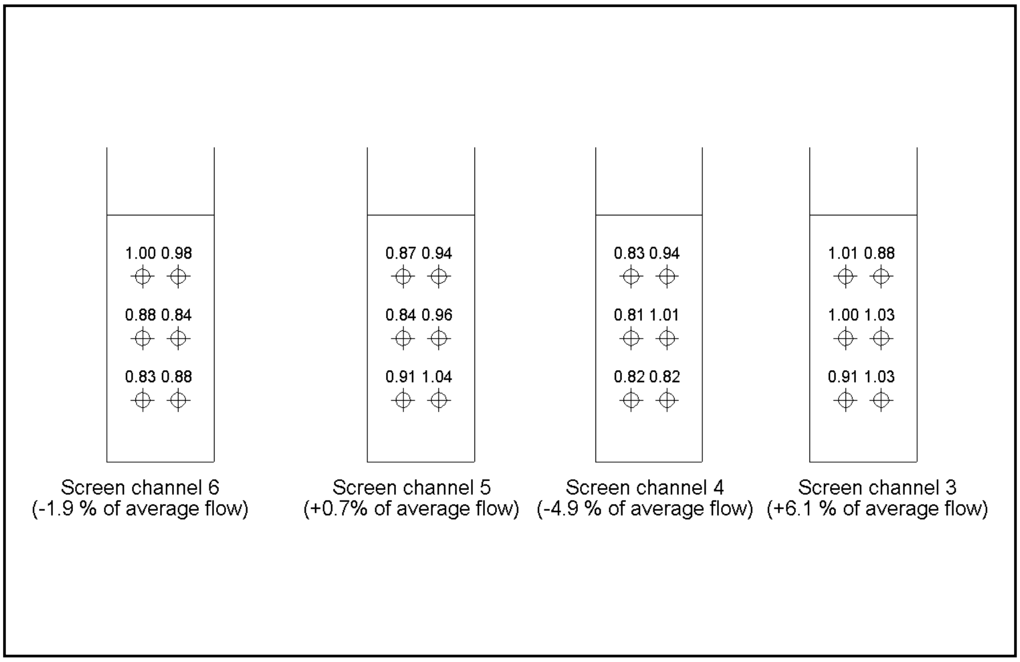

Figure (9) Velocity Distribution Pattern

▪ RESULTS & DISCUSSIONS

The Model Testing illustrated that although the energy was successfully dissipated from the inflow, immediately downstream of the inlet within the forebay, velocities on approach to the screen channels remained excessive. Therefore the unacceptable distribution of flow was observed through selected screen channels during asymmetric operation of the station. During the operation, the two central screen channels (Screen channel 3 and 4) were observed to take a maximum deviation of 46% from the average calculated flow. Symmetrical operation of the screen channels was observed to result in an acceptable distribution of flow, with a maximum deviation from the average flow of -9.5%.

All pumps to be free of coherent submerged vortices during operation of the design flow of 12 m^3/s. However, unacceptable levels of pre-swirl rotation were observed at pumps located toward the centre of the station due to the orientation of flow as it entered each of the sumps. Flow on entry to sumps A and C resulted in rotation (anti-clockwise in Sump A and clockwise in sump C), resulting in variations in velocity through each of the ports within the baffle wall. This imbalance in inflow between the ports resulted in cross flow between the pumps and therefore increased levels of pre-swirl rotation of selected pump units. The highest pre-swirl rotation was recorded in Sump A, at pumps A2, A3 and A4.

Excessive momentum on approach to sump B resulted in excessive velocities through the central parts within the baffle wall, again creating an imbalance of flow across the sump, which resulted in high levels of pre-swirl rotation at pumps B3 to B6 in particular. The maximum pre-swirl rotation recorded was 7.7 degrees, with the highest levels of pre-swirl rotation generally been recorded at the pumps closest to the centre line of the station.

With regard to submerged vorticity, the ANSI standard states [1] & [3], ‘Submerged vortices should not exceed Type 2 classification.’ With regard to pre-swirl rotation the ANSI standard states, ‘The maximum permitted swirl angle should be 5.0 degrees for both short term and long term average conditions, whilst 7.0 degrees has been defined as acceptable as a short term maximum value for infrequent occurrence (<10% time) [6].

Final testing observed acceptably balanced flows across each of the screen channels following development within the forebay. The maximum deviation from the calculated mean flow following development was observed to be 6.1 %. Final testing also went on to verify that an acceptable split in flow between each of the screen channels was achieved using detailed velocity plots at 6 m3/s and 2 m3/s, and across the full range of operational flows using dye tracing.

Developments (flow deflectors, reduced port heights and kicker blocks) were observed to reduce pre-swirl rotation to within acceptable limits across the full operating range of the station, with the maximum pre-swirl rotation recorded as 4.4 degrees.

During final testing across the full operating range of the pumping station, surface vorticity was observed at low level during 1 m3/s to 2 m^3/s operation, at pumps toward the edge of the sumps (i.e. A1 or A8, B1 or B8). Further development was therefore recommended to reduce the height of the vanes opposing each of the pumps by 500 mm. This eliminated the occurrence of coherent surface vorticity across the full operating range.

▪ CONCLUSION

a. Three different flow scenarios had been observed (min. 2 m^3/s), (average 6 m^3/s) and (max. 12 m^3/s) which cover the design flow conditions.

b. Final testing showed some pump combinations of lower water levels to result in higher levels of pre-swirl rotation.

c. All pre-swirl are within acceptable limits, we selected the pump type which results up to pre-swirl value (5 degrees).

d. The testing and demonstration of the model proved the suitability of the pumping station configuration as per the applied developed model arrangements and plan setting geometry.

e. The model testing has confirmed the general arrangement of the pumping station and identified various minor improvements.

REFERENCES

ANSI/HI 9.8, 1998 Hydraulic Institute "American National Standard for Pump Intake Design." Parsippany, NJ, USA.

Chen Y., Wu Ch., Ye M., Ju X. (2007) Hydraulic Characteristics of Vertical Vortex at Hydraulics Intakes Journal of Hydrodynamics, Ser.B, 2007,19(2):143-149.

FLYGT Pump Division "Test Standards for Pump Model Intakes." 2002.

H. Rouse, Handbook of Hydraulics, Wiley, New York.

ISO International Standardization Organization 13709, 2007 "Centrifugal Pumps"

The Technical Writers Handbook. Mill Valley, CA: University Science, 1998.